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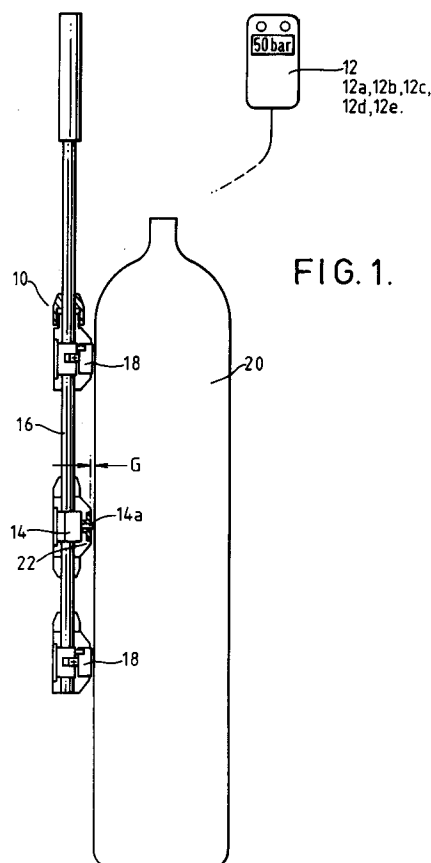
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**Surrey GU20 6HJ (GB)**(54) **Method and apparatus for determining the internal pressure of a sealed container.**

(57) Apparatus (10) includes means (14) for exciting at least the fundamental radial circumferential mode of vibration ( $f_1$ ) and the first harmonic ( $f_2$ ) thereof, detection means (22) for detecting the vibration and analysing means (12) for determining the internal pressure by reference to  $f_1$  and  $f_2$ .

**FIG. 1.****EP 0 681 168 A2**

The present invention relates to a method and apparatus for determining the internal pressure of a sealed container, and is more particularly concerned with a method and apparatus for non-destructively determining the internal pressure of a sealed gas bottle by analysing the vibratory mode thereof.

Presently known methods of determining the internal pressure of a gas bottle include the use of a pressure gauge. The gauge is connected to the outlet of the bottle prior to the operation of a valve which allows the gauge to communicate directly with the contents of the bottle and respond to the pressure therein. Such gauges, whilst providing a high degree of accuracy, when correctly fitted by a skilled operator, do not lend themselves to the speedy operation. This can cause undesirable delays when an operator is checking a large number of bottles. In fact, the accuracy of such gauges can be an immaterial advantage when, for example, it is merely desired to check whether the bottle is substantially full or substantially empty, thereby to avoid an empty bottle being despatched to a customer.

There therefore exists a requirement for a method of and apparatus for determining the internal pressure of a sealed container, such as a bottle, which is comparatively quick to use and which does not rely on the skill of the operator to ensure an accurate measurement. An additional requirement which the present invention aims to achieve is to provide an apparatus which is easily accommodated in the relatively small gap between closely packed bottles.

Accordingly, the present invention provides a non-invasive method of determining the pressure within a container comprising the steps of:

- (a) imputing container data into a memory;
- (b) Striking the container in a controlled manner so as to excite the fundamental radial-circumferential mode of vibration ( $f_1$ ) and the first harmonic thereof ( $f_2$ );
- (c) detecting the vibration resulting from the striking of said container;
- (d) producing a frequency spectrum of the detected vibration
- (e) isolating the frequency of the fundamental mode ( $f_1$ ) and the second harmonic ( $f_2$ ) from the frequency spectrum
- (f) calculating the internal pressure P from the isolated values of  $f_1$  and  $f_2$

It will be appreciated that all the above mentioned calculations may be made by a simple calculating device and that, as a result of this, and the fact that the method avoids the problems associated with pressure gauges, it will be possible for an unskilled operator to undertake pressure measurement at comparatively high speed.

In another aspect of the present invention there is provided an apparatus for the non-invasive determination of pressure within a container, said apparatus comprising:

- (a) means for receiving basic container information;
- (b) striking means for striking the container in a controlled manner so as to excite the fundamental radial-circumferential mode of vibration ( $f_1$ ) and the first harmonic thereof ( $f_2$ );
- (c) detecting means for detecting vibration resulting from the striking of said container;
- (d) isolating means for isolating the values of  $f_1$  and  $f_2$
- (e) calculating means for calculating the internal pressure P from the isolated values of  $f_1$  and  $f_2$

The present invention will now be more particularly described by way of example only with reference to the following drawings, in which;

Figure 1 is a side view of an apparatus according to the present invention shown attached to a bottle;

Figures 2 and 3 are graphs of received vibration signals;

Figure 4 is a graph of vibration frequency against pressure for a bottle at various pressures; and

Figure 5 is a flow diagram relating to the pressure calculation software.

Referring to Figure 1, the apparatus 10 comprises a data storage and processing device such as, for example, a hand held data acquisition unit 12 to be described in detail below and a solenoid or manually activated striker 14. The striker 14 may be mounted on a support member 16 in the form of an elongate member or rod having one or more magnets 18 for securing the rod support member 16 to a bottle 20 to be tested. For convenience, one of said magnets may be slidable up and down said support member 16 so as to facilitate the accommodation of various sizes of bottle 20. The striker 14 is mounted relative to said support member 16 and magnets 18 so as to leave a gap G between the end 14a of the striker 14 and the bottle when said striker is in a retracted position. A signal detector in the form of accelerometer 22 is provided for detecting vibration within the bottle set up as a result of the operation of striker 14. The accelerometer is linked to the data acquisition unit 12 for the transfer of data thereto.

The data acquisition unit (DA Unit) 12 includes an analogue to digital converter 12a, a memory 12b to store captured and processed data, a processor 12c for processing data in a manner to be described later herein, a simple keypad and display 12d and a power supply 12e. The DA Unit 12 may further include a capability for storing results and/or down-loading data over a serial communica-

tions link (not shown). Typically, the signal processing capability will include filtering by a low-pass digital filter with cut off set to about 3.5 KHz and means for conducting a Fast Fourier Transform on the data.

The present invention being particularly slim lends itself to insertion into the small gaps formed between closely packed cylindrical bottles. In which position the striker 14 is located towards the mid portion of the bottle so as to minimise the effects of the bottle ends on the pressure determining method.

Referring now to Figures 1 to 5 the present apparatus 10 is operated by firstly selecting the appropriate bottle size from a range stored in the memory or imputing data manually thereby to access the basic data relating thereto (step A); striking the bottle 20 with striker 14 so as to excite at least the fundamental radial circumferential mode of vibration ( $f_1$ ) and the first harmonic ( $f_2$ ) thereof; detecting the vibration (Fig. 2, 3) within the bottle 20 through accelerometer 22 (step B); conducting an analogue-to-digital conversion to between 8 and 12 bit resolution (step C) and presenting the converted signal to the DA Unit 12 for processing. Processing includes the steps of cleaning up the received signal by means of, for example, a fast fourier transformation technique (step D) and then isolating the values of  $f_1$  and  $f_2$ . Isolation of  $f_1$  and  $f_2$  may be conducted by selecting the ten most pronounced resonance peaks from the cleaned up signal (step E) and searching for and identifying those peaks that correspond to the  $f_1$  and  $f_2$  peaks. Preferably the search and identify routine involves the following steps:

(a) estimating the value of  $f_1$  ( $f_1(\text{est})$ ) and then searching for the real value of  $f_1$  within a given range R of said estimated value (see Fig 4)  $f_1(\text{est})$  being established by the following steps (step F):

- (i) selecting a nominal value of bottle thickness ( $t_0$ ) from stored or manually imputed data.
- (ii) calculating a nominal value of A ( $A_0$ ) from, for example

$$A_0 = C_1 \times 0.49 \sqrt{\left( \frac{Et_0^2}{\rho d^4} \right)}$$

(iii) estimating  $f_1(\text{est})$  from  $f_1(\text{est}) = A + Bp$  where Bp is given a value of zero.

(b) estimating the value of  $f_2$  ( $f_2(\text{est})$ ) and then searching for the real value of  $f_2$  within a given range of said estimated value (see Fig 4);

$f_2(\text{est})$  being established from, for example,

$$f_2(\text{est}) = 2.8 \times A_0 - f_1 \text{ (step G)}$$

Upon identification of the real values of  $f_1$  and  $f_2$  (step H) the real value of A may be calculated from, for example,

$$A = (f_2 - f_1) / 2.8$$

The bottle wall thickness t may then be calculated from, for example;

$$A = C_1 \times 0.49 \sqrt{\left( \frac{Et^2}{\rho d^4} \right)}$$

After calculation of the wall thickness t, the variable B may be calculated from, for example;

$$B = C_2 \times \frac{0.05d}{t^2} \sqrt{\left( \frac{1}{\rho E} \right)}$$

and then the pressure P within the container may be calculated from

$$P = (f_1 - A) / B \text{ (step I)}$$

The results of the calculations may be presented to the operator (step J) via hand held DA Unit 12 or via a computer printout (not shown). Clearly, it will be possible to adopt a number of different calculating methods and hence the present invention is not considered to be limited to those presented herein.

## Claims

1. A non-invasive method of determining the pressure within a container characterised by the steps of:

- (a) imputing container data into a memory;
- (b) Striking the container in a controlled manner so as to excite the fundamental radial-circumferential mode of vibration ( $f_1$ ) and the first harmonic thereof ( $f_2$ );
- (c) detecting the vibration resulting from the striking of said container;
- (d) producing a frequency spectrum of the detected vibration
- (e) isolating the frequency of the fundamental mode ( $f_1$ ) and the second harmonic ( $f_2$ ) from the frequency spectrum

(f) calculating the internal pressure P from the isolated values of  $f_1$  and  $f_2$

2. A method as claimed in Claim 1 characterised by the further steps of:

(a) calculating the value of variable A from the following equation

$$A = (f_2 - f_1) / 2.8$$

(b) calculating the thickness t of the container from the following equation

$$A = C_1 \times 0.49 \sqrt{\left( \frac{Et^2}{\rho d^4} \right)}$$

(c) calculating the variable B from the following equation

$$B = C_2 \times \frac{0.05d}{t^2} \sqrt{\left( \frac{1}{\rho E} \right)}$$

and then;

(d) calculating the pressure (P) within the container from equation

$$P = (f_1 - A) / B$$

in which,

t = the thickness of the container wall

d = the diameter of the container

E = the Elastic Modulus of the container

$\rho$  = the density of the container material

$C_1$  and  $C_2$  are correction factors to correct for the effect the ends of the container has on the calculation.

3. A method as claimed in Claim 1 or Claim 2 characterised in that  $f_1$  and/or  $f_2$  are isolated by searching within a pre-determined frequency range or ranges.

4. A method as claimed in Claim 1 or Claim 2 characterised in that  $f_1$  is isolated by first estimating a value of  $f_1$  ( $f_1(\text{est})$ ) and then searching for the real value of  $f_1$  within a given range of said estimated value,  $f_1(\text{est})$  being established by the following steps:

(a) selecting a nominal value of thickness ( $t_0$ )

(b) calculating a nominal value of  $A(A_0)$  from

$$A_0 = C_1 \times 0.49 \sqrt{\left( \frac{Et_0^2}{\rho d^4} \right)}$$

(c) estimating  $f_1(\text{est})$  from

$$f_1(\text{est}) = A + Bp$$

Where  $Bp$  is given a value of zero

5. A method as claimed in Claim 1 or Claim 2 characterised in that  $f_2$  is isolated by first estimating a value of  $f_2$  ( $f_2(\text{est})$ ) and then searching for the real value of  $f_2$  within a given range of said estimated value,  $f_2(\text{est})$  being established from

$$f_2(\text{est}) = 2.8 \times A_0 - f_1$$

Where  $A_0$  is the nominal value of A calculated in accordance with Claim 3 and  $f_1$  is the actual value of the fundamental radial-circumferential mode of vibration.

6. An apparatus (10) for the non-invasive determination of pressure within a container, said apparatus being characterised by:

(a) means (12) receiving basic container information;

(b) striking means (14) for striking the container in a controlled manner so as to excite the fundamental radial-circumferential mode of vibration ( $f_1$ ) and the first harmonic thereof ( $f_2$ );

(c) detecting means (22) for detecting vibration resulting from the striking of said container;

(d) isolating means (12c) for isolating the values of  $f_1$  and  $f_2$

(e) calculating means (12c) for calculating the internal pressure P from the isolated values of  $f_1$  and  $f_2$

7. An apparatus as claimed in Claim 5 further characterised in that said calculating means (12c) calculates the values of A, t, B and P from the following equations:

$$A = (f_2 - f_1) / 2.8$$

$$A = C_1 \times 0.49 \sqrt{\left( \frac{Et^2}{\rho d^4} \right)}$$

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$$B = C_2 \times \frac{0.05d}{t^2} \sqrt{\left( \frac{1}{\rho E} \right)}$$

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Where

A and B are correction factors

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t = the thickness of the container wall

d = the diameter of the container

E = the Elastic Modulus of the container

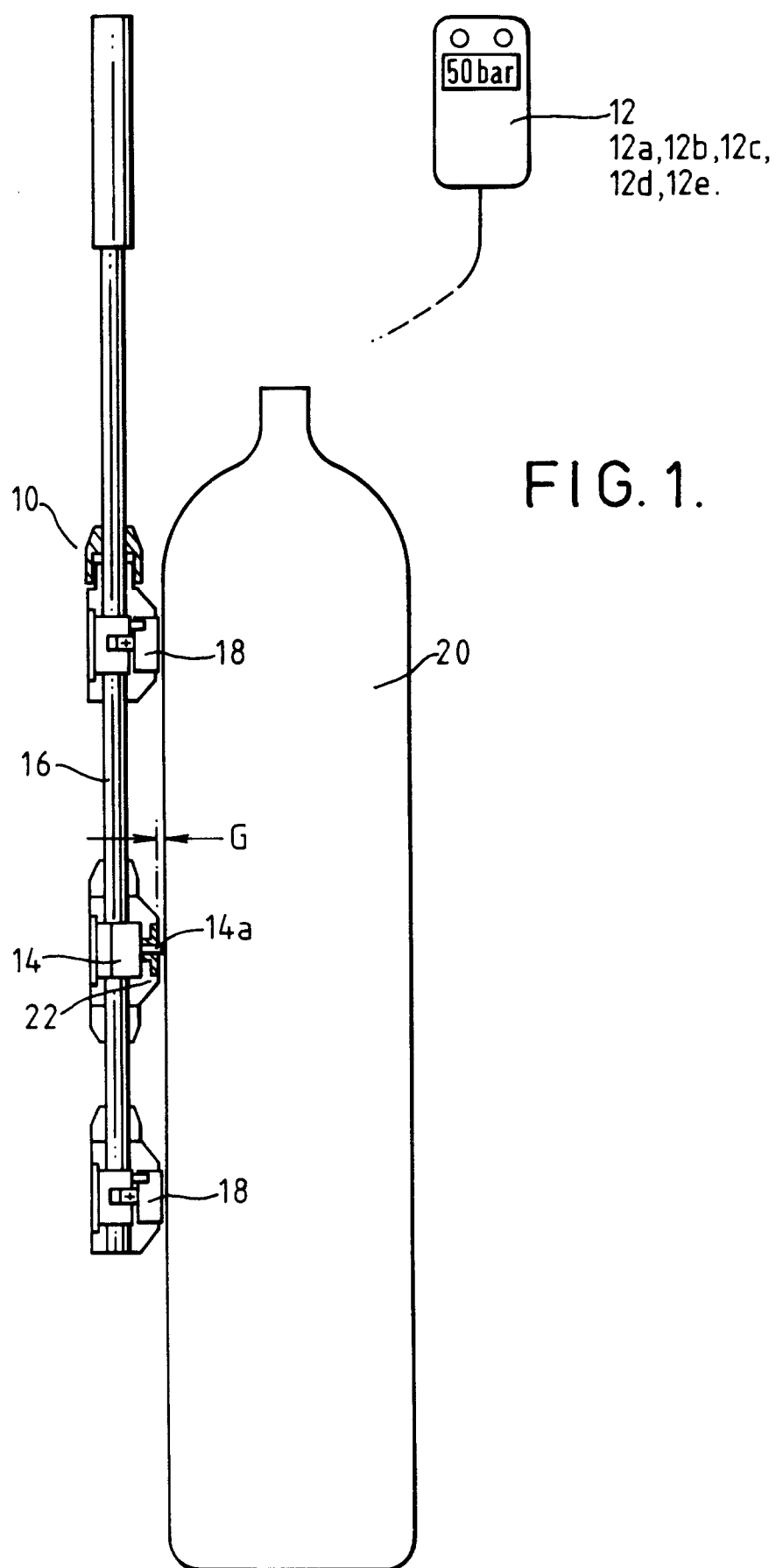
$\rho$  = the density of the container material

C<sub>1</sub> and C<sub>2</sub> are correction factors to correct for the effect the ends of the container has on the calculation.

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8. An apparatus as claimed in Claims 5 or 6 further characterised by a support member (16) on which said striking means (14) is mounted and securing means (18) for securing said support member to said container. 25
9. An apparatus as claimed in Claims 5 or 6 characterised in that said support member (16) comprises an elongate member sized for enabling its insertion between closely packed cylindrical containers (20). 30
10. An apparatus as claimed in Claim 6, 7 or 8 characterised in that said securing means (18) comprises a pair of magnets which in operation act to magnetically clamp the support member to said container (20). 35 40
11. An apparatus as claimed in any one of Claims 5 to 9 characterised in that said striking means (14) comprises a solenoid having a striking member (14a) which in operation is held away from the surface of the container (20) to be struck and released for striking said container (20) when it is desired to cause vibration thereof. 45 50
12. An apparatus as claimed in any one of Claims 5 to 10 characterised in that said detecting means comprises an accelerometer. 55

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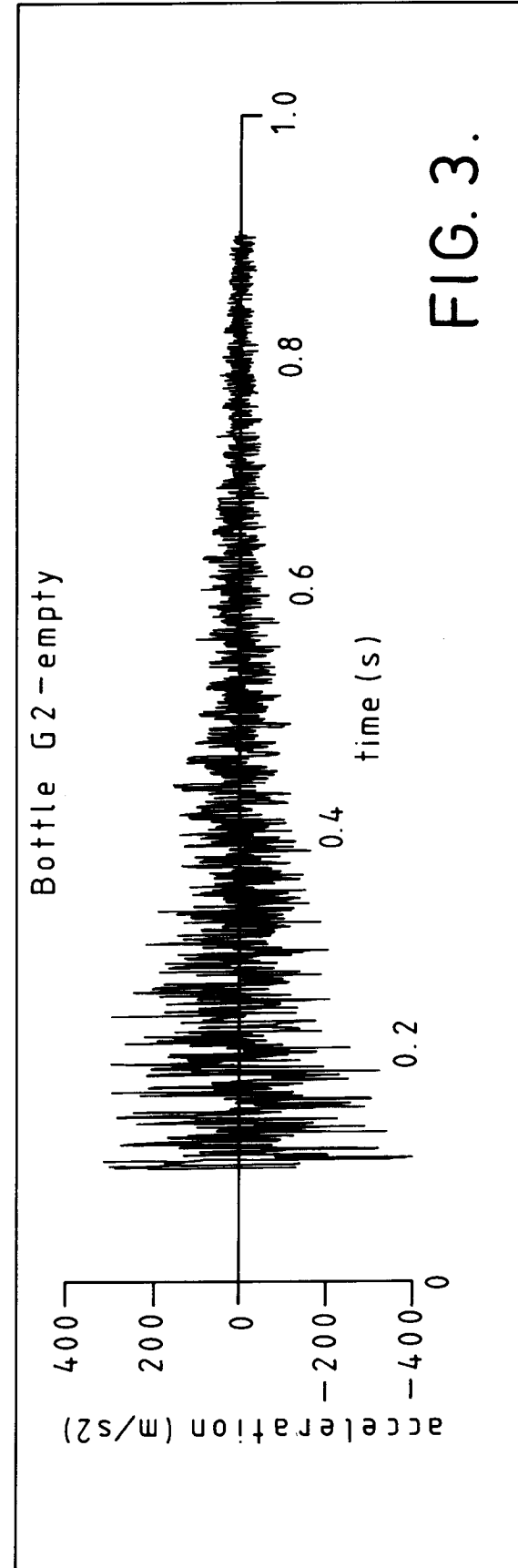
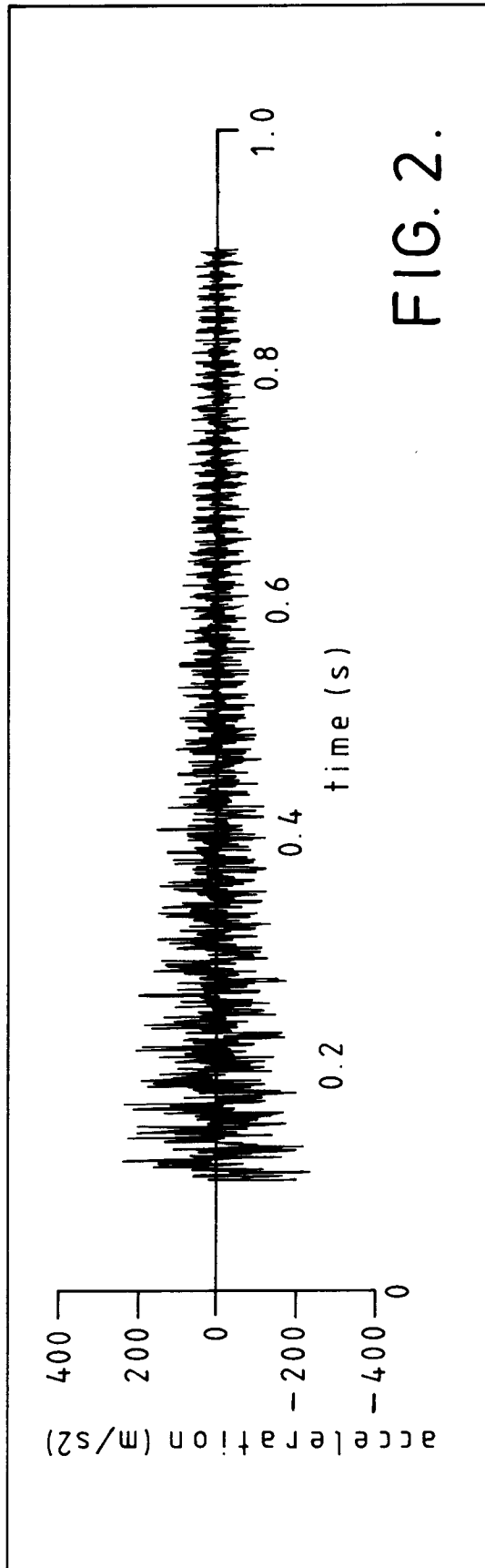


FIG. 4.

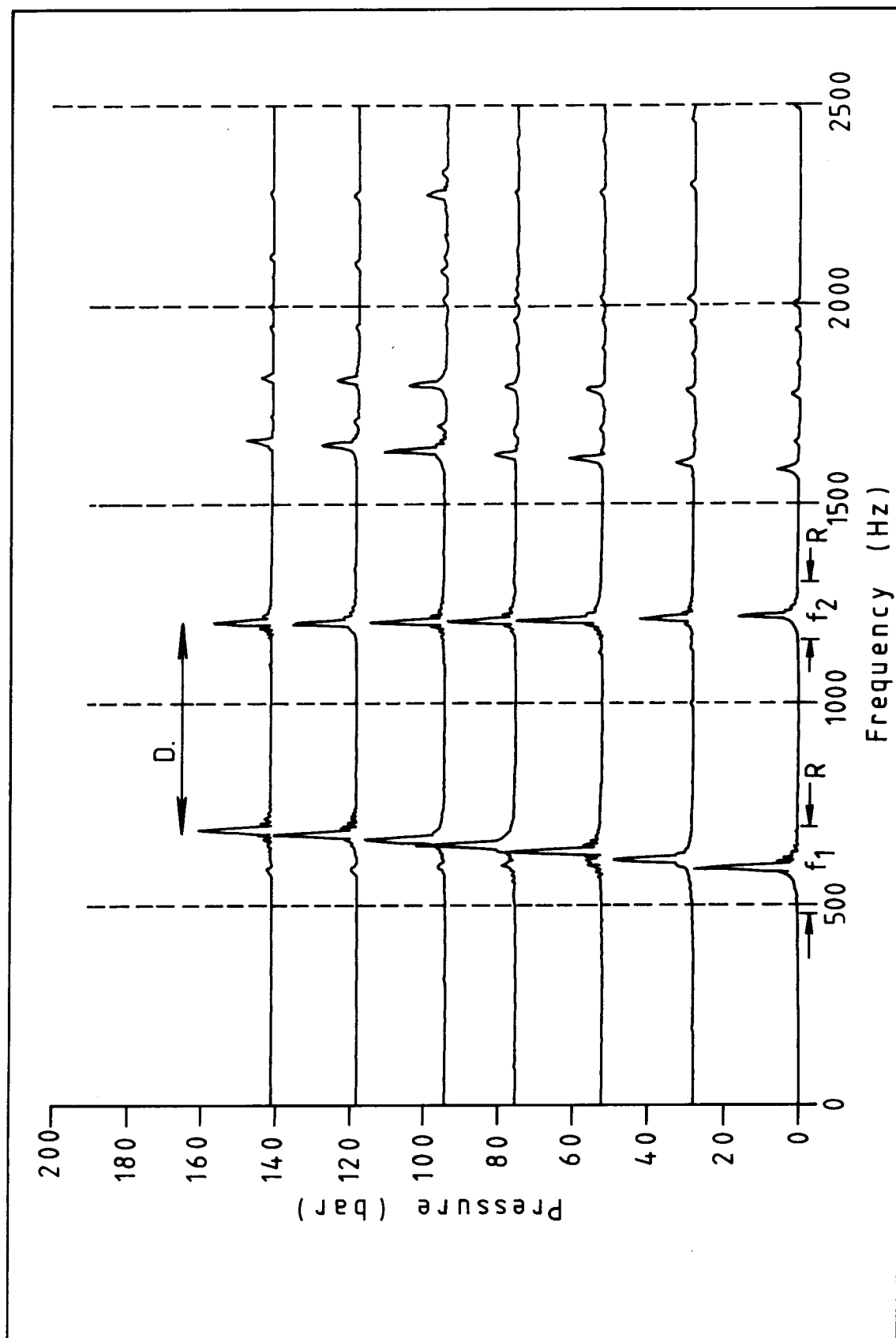




FIG. 5.

